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Amorphous Finemet films for visualization of inhomogeneous magnetic fields

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Abstract. This paper shows that amorphous Finemet films can be used as a medium for visualization and topography of inhomogeneous magnetic fields. The intensity of magneto-optical images obtained in the geometry of the polar magneto-optical Kerr effect is proportional to the normal component of the inhomogeneous magnetic field. This allows us to construct two-dimensional topograms of the normal component of the magnetic field. The images observed in the geometry of the longitudinal magneto-optical Kerr effect carry information about the planar component of the field. The vector field of the plane component has singular points that are displayed by magneto-optical images. Applying an external homogeneous field leads to the appearance of new singular points and their motion. At special points, the plane component of the field is equal to the value of the external field. This allows you to display a planar component by recording the coordinates of specific points.

1. Introduction

Magneto-optical images of the normal component of the inhomogeneous magnetic field can be used to determine the characteristics of the field sources [1, 2]. Magneto-optical visualization of inhomogeneous field obtained by Faraday effect has a limitation associated only with the registration of the normal component of the field. The application of metal FeCo films with plane anisotropy extends the possibilities of field visualization using the Kerr effect, since magneto-optical field images contain information about the vertical and plane components of the field [3]. A comparison of the magneto-optical images (MOIs) experimentally observed in the metal films with plane anisotropy with a inhomogeneous field model images shows presence of the singular points corresponding to the singular points (So - «source», Si - «sink» and Sa - «saddle») of the plane component of the inhomogeneous field [3]. In [3] the idea of topographing the plane component of the field is expressed by fixing the coordinates of the singular points as the external uniform plane field changes. The FeCo films have a large anisotropy in the plane and significant coercivity of domain walls that prevents an adequate display of an inhomogeneous magnetic field. We propose to use Finemet films featuring low anisotropic and low coercive force for visualization and topography of inhomogeneous magnetic fields. We focused our attention on experimental observations of the motion of singular points under the action of a uniform external field and the possibility of constructing topograms of plane components of a non-uniform field.

2. Experimental techniques and modelling

As a source of inhomogeneous magnetic field, we used a magnet having the shape of a rectangular parallelepiped with dimensions of $a \times b \times c = 2 \times 1 \times 0.5$ and $2 \times 1.5 \times 0.5$ mm. The faces of the magnets were



polished to obtain the desired shape and size. The magnetization was measured using vibrating sample magnetometer ($M_s = 500 \text{ G/cm}^3$). The low value of magnetization is explained by influence of the mechanical treatment.

Figure 1 shows diagram of magneto-optical installation and mutual orientation of magnetic moment of magnet and external homogeneous magnetic field. Magnetic moment of the magnet was oriented perpendicular to the observation plane for mapping the normal field component. For mapping the plane component, the magnetic moment was oriented parallel to the observation plane. The MOI of inhomogeneous magnetic fields in magnetic metal films were observed applying the longitudinal Kerr effect with the use of *s*- and *p*-polarized light. We used the standard MO imaging setup for the large view magnetic domain observations.

As an indicator media (indicator film) we used 80 nm thick amorphous Finemet ($\text{Fe}_{73.5}\text{Cu}_1\text{Nb}_3\text{Si}_{13.5}\text{B}_9$) films with in-plane anisotropy. The film was deposited onto the 0.27 mm glass substrate by high-frequency magnetron sputtering. Magnetization of the film was 900 G/cm^3 . The easy magnetization axis was induced during the film deposition by applying the plane magnetic field. The anisotropy field and coercivity (H_c) of the film were 6 and 1.5 Oe, accordingly. An additional in-plane external magnetic field was applied perpendicular to the easy magnetization axis. To increase the magneto optical contrast, an additional ZrO_2 layer of the thickness of $L = \lambda/4n = 90 \text{ nm}$ was deposited on top magnetic layer. Here λ is the wavelengths of light, n - the refractive index of ZrO_2 layer.

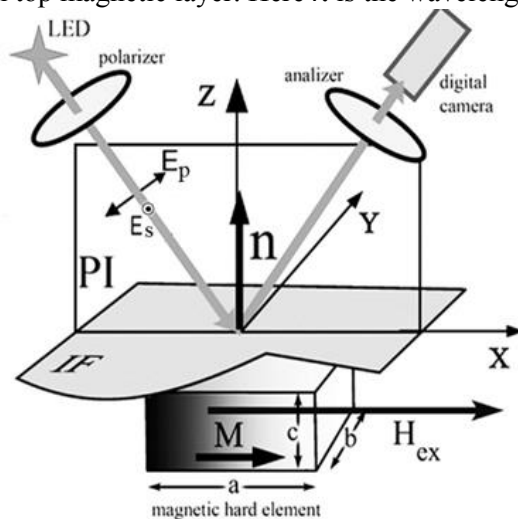


Figure 1. Diagram of magneto-optical installation and mutual orientation of magnetic moment of magnet and external homogeneous magnetic field. Arrow E_p and E_s marked the axis of polarization of *p*- and *s*-polarized light; PI - plane of incidence, LED - light-emitting diode.

To determine the adequacy of the inhomogeneous field mapping by magneto-optical images, we performed calculations of the magnet field and modeling of the expected MOIs using Mathcad software package according to the method proposed in [5].

3. Results and discussion

The principles of topography consist in the quantitative analysis of MOIs in polar sensitivity and in longitudinal sensitivity. Visualization and topography of the vertical field component (H_z , figure 2a) showed the result similarly to experiments on field mapping using polycrystalline FeCo films [6] (figure 2b, c). MOIs in polar sensitivity reflect the spatial distribution of H_z -components by brightness gradations: $I = kH_z$, where I is the intensity (brightness) of MOI, k - the coefficient depending on the magneto-optical q -factor of the indicator film (figure 2b). MOI of the plane component of the field (figure 2d) in longitudinal sensitivity reflects the angular distribution of the plane component of a non-uniform field by gradations of brightness and the presence of singular points (figure 2e). In the absence of an external field under these experimental conditions, one singular point of type-Si is observed above the center of the magnet. The presence of such a singular point characterizes the dipole property of a magnet [3]. The action of an external homogeneous field parallel to the observation plane forms a singular point of type-Sa (figure 2e). At singular points, the values of the planar field (H_p) components

are known ($H_x = -H_{\text{xex}}$, $H_y = -H_{\text{yex}}$). Here H_{xex} , H_{yex} are the components of the external homogeneous field (H_{ext}).

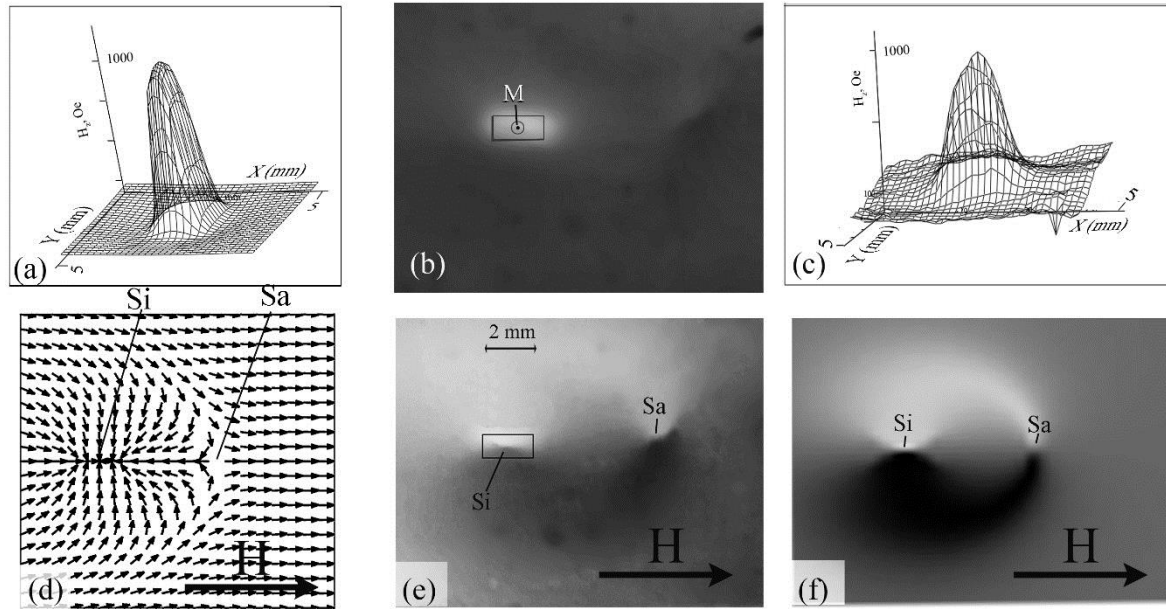


Figure 2. Calculated two-dimensional dependence of the H_z -component of a rectangular magnet (a), (b) MOI of the magnet field and the corresponding experimental topogram of the field (c), (d). Vector directional diagram of the plane component of the field and the corresponding experimental (e) and model (f) MOIs. The magnet contour is shown in (b) and (c). The moment of the magnet is oriented perpendicular to the plane of observation.

Significant differences between the FeCo and Finemet films are manifested in MOI of planar component of the inhomogeneous field. The results of our experiments showed that the MOI of the planar components of the inhomogeneous field in polycrystalline FeCo films do not coincide with the model ones. This is due to the large coercive force and the field plane anisotropy of these films. The Finemet films have a lower coercive force and an anisotropy field; therefore, MOI satisfactorily reflects the distribution of the planar component. Figures 2e and 2f show a comparison of model and experimental MO images. It can be seen that the experimental images adequately reflect the distribution of the plane component of the field.

The topography of planar component is supposed to be carried out by fixing the coordinates of the singular points as they move in the presence of an external uniform field. At singular points, $H_p = -H_{\text{ext}}$, which makes it possible to construct the dependence $H_p(x, y)$ as the external field changes.

As an example, the movement of singular points of MOI of rectangular magnet field is shown in figure 3. In the absence of an external field, two singular points of the “source” and “sink” type are formed (So, Si, figure 3a). These singular points characterize the dipole character of the magnet at a given orientation. The application of an external field along the axis of the magnet texture in the positive direction forms singular points of the “saddle” type (Sa, figure 3b). The formed petals are reduced by moving the type-Sa singular points towards each other (figure 3c) along the line perpendicular to the orientation of the external field. The field action in the opposite direction causes the appearance of singular points on the axis parallel to the texture axis (figure 3d). The growth of the field causes the movement of the formed points along this line (figure 3e, f). The superposition of the fields of H_x , H_y leads to a change in the orientation of the axis on which the singular points are formed. This makes it possible to obtain dependencies (H_x , H_y) on the entire coordinate plane.

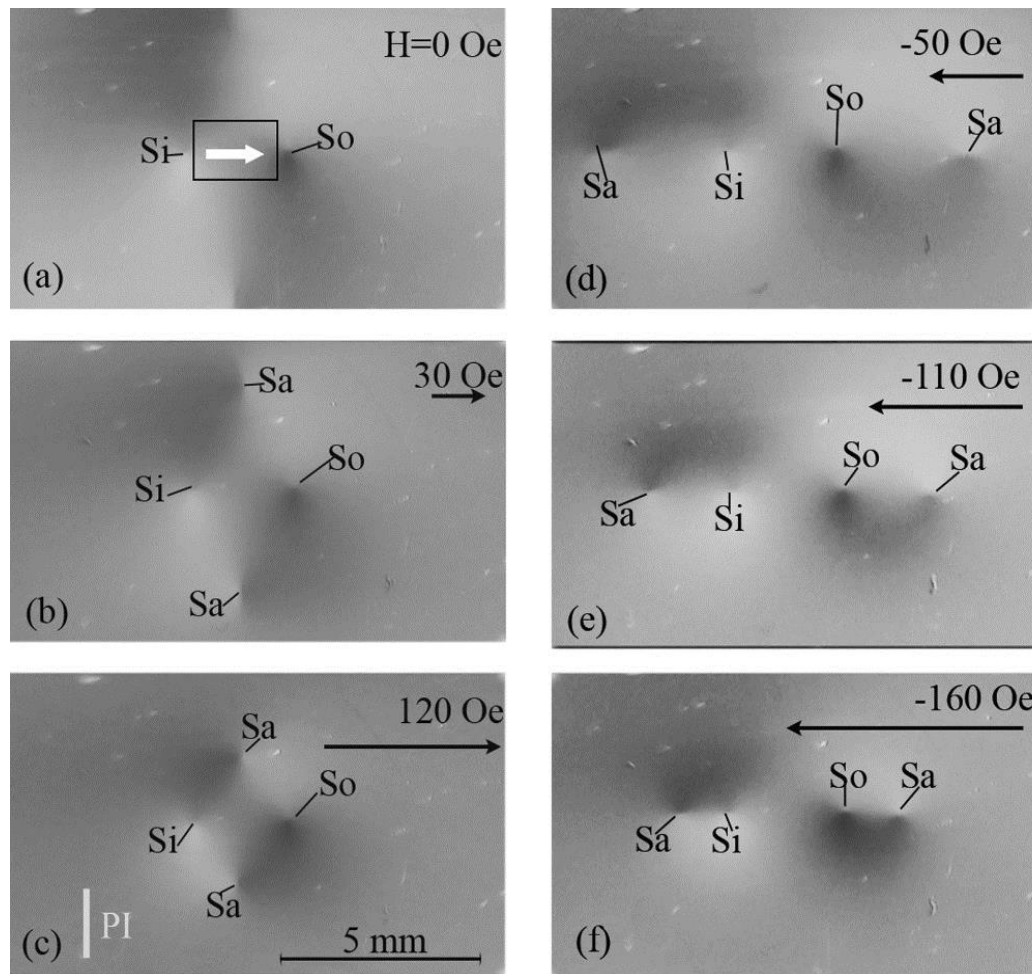


Figure 3. The change MOI of the field of a rectangular magnet in the presence of an external uniform field oriented along the X- axis. The PI bar shows the orientation of the plane of incidence of light. The moment of the magnet is oriented parallel to the plane of observation (white arrow on (a)).

Figure 4 demonstrates the experimental one-dimensional dependencies of $H_x(x, y = 0)$ and $H_x(x = 0, y)$. The solid line shows the coordinate dependencies of the field components calculated according to the known formulas for a rectangular magnet. The qualitative agreement of experimental and theoretical topograms is seen. This confirms the viability of the proposed planar component topography algorithm. However, there is a significant spread of experimental points and deviations from the calculated curves. The large error in determining the coordinates of singular points is related to the error in localizing singular points.

4. Conclusions

It is shown that amorphous Finemet films are suitable for visualizing and mapping the normal and planar components of a non-uniform magnetic field. The planar component is represented by brightness gradations and the movement of singular points in the presence of an external uniform field. One-dimensional topograms constructed by fixing the coordinates of singular points for given values of the external field are in satisfactory agreement with the calculated dependencies.

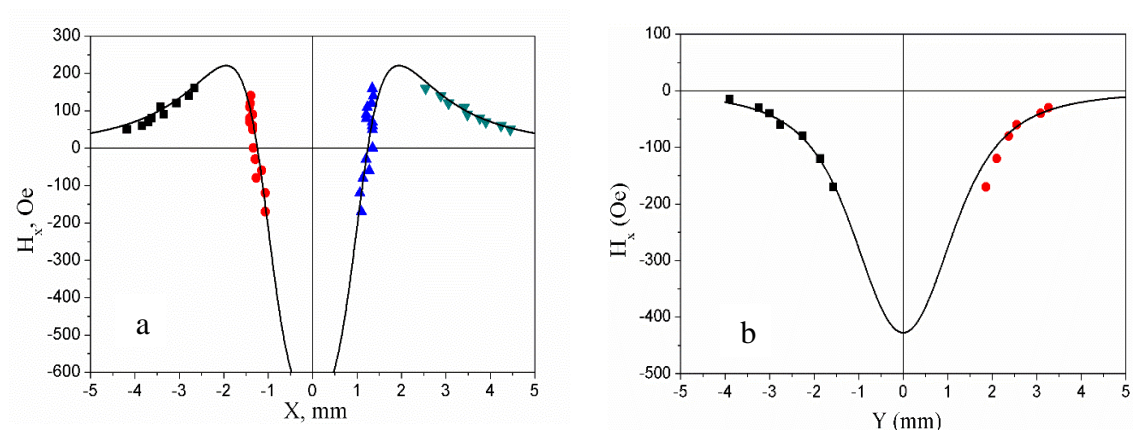


Figure 4. Experimental one-dimensional topograms of $H_x(x)$ (a) and $H_x(y)$ (b). The solid line shows the calculated dependences.

Acknowledgments

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